A Method for In-Place Mix Control in Reconstruction of Soil-Aggregate Roads

J. B. SHEELER, Associate Professor of Civil Engineering, Iowa State University

The design method in this paper is specific for the case in which an old aggregate surface is to be scarified and incorporated in the new surface and the binder material is taken from the roadbed. The quantities of existing material are calculated from trench sample data. Equations are presented from which quantities of additional material are calculated and spotted. Quantitative control is accomplished by requiring a percentage of material finer than some specific size in the final mixture. The quantities also depend on the dimensions desired.

• SEVERAL METHODS of blending natural soil materials are used in the construction of the wearing surface for secondary roads. In the most common methods an aggregate and an imported clayey soil are mixed by some means on a newly constructed grade or the materials are plant-mixed before placement. The methods for proportioning materials are well established for soil aggregate mixtures, and the stationing of materials for the preceding construction procedures is easily calculated. An excellent method of blending natural earth deposits is given by Ritter and Shaffer (5). The method requires an electronic computer and uses linear programming for determining materials and sources for least cost. Inasmuch as most county engineers do not have ready access to an electronic computer and are not trained in linear programming, this method is somewhat limited in use for secondary road construction.

In another method of secondary road construction a worn soil-aggregate surface is salvaged; the old surface is scarified, new aggregate is added to the old material, and the deficiency of fine binder material in the resulting mixture is corrected by incorporating some soil from the subgrade. Usually the soil from the subgrade is loosened during the scarification process and is bladed into a windrow with the salvaged aggregate before the new material is added. This paper describes a rational method of determining the material placement needed to obtain a reasonably uniform thickness and gradation throughout a roadway to be constructed by the procedure just described. The method may also be used in chemical stabilization of soil-aggregate materials.

DEVELOPMENT OF EQUATIONS

In the utilization of granular surface material in the construction of new surface courses the engineer has problems of quality and quantity control. Because the amount of granular material varies from place to place, the cross-sectional area of the granular material varies throughout the length of a road. Therefore, if the surface is scarified to a constant depth over the length of the road, the amount of soil scarified from the subgrade will vary from place to place, and the amount of fines in the mixture will vary considerably. This variation can be greatly reduced by creating a constant cross-sectional area of granular material over the length of the road. Scarification to a constant depth will then produce a constant cross-sectional area of loosened subgrade soil, and the amount of fines will be relatively constant over the entire road.

The amount of granular material located at all points on a road must be known in order to have control over the quantities of material involved at any point in question. The amounts of granular materials may be determined by digging trenches normal to

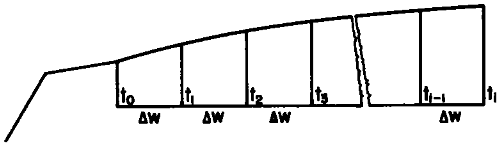

Figure 1. Cross-section of sampling trench showing meaning of symbols and subscripts used in calculating average thickness of granular material.

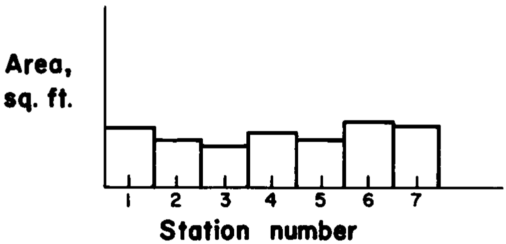

Figure 2. Histogram of trench sample data Trenches are located at mid-point of each section and identified by station number

the centerline of the road. A determination of the exact amount of material is out of the question because of the great number of trench samples required. Therefore, some accuracy must be sacrificed in the interests of economy, trench samples must be taken at intervals and assumed to be representative of their respective intervals.

The cross-sectional area of granular material at each trench sample location may be determined by dividing the length of the trench into i subintervals Δw long, and measuring the thickness t at each of these subintervals as shown in Figure 1. The total cross-sectional area is then the summation of the small areas. However, it is more convenient and useful to measure the full width of the granular material and to determine an average thickness as follows:

The area of increment No. 1 is $(\frac{t_0+t_1}{2})\Delta w$, if the increment is considered to be trapezoidal, that of increment No. 2 is $(\frac{t_1+t_2}{2})\Delta w$, and so on. The total area is then

$$\text{Area} = \frac{t_0+t_1}{2}\Delta w + \frac{t_1+t_2}{2}\Delta w + \dots\dots\dots\dots + \frac{t_{i-1}+t_i}{2}\Delta w$$

$$= \Delta w\left(\frac{t_0}{2}+\frac{t_1}{2}+\frac{t_1}{2}+\frac{t_2}{2}+\frac{t_2}{2}+\dots\dots+\frac{t_{i-1}}{2}+\frac{t_{i-1}}{2}+\frac{t_i}{2}\right)$$

$$= \Delta w\left[\frac{t_0+t_i}{2} + \sum_{i=1}^{i-1} t_i\right] \quad (1)$$

The area can also be expressed in terms of an average value of thickness, t_{avg}:

$$\text{Area} = (i)\,(\Delta w)\,t_{avg} \quad (2)$$

Equating Eqs. 1 and 2 gives

$$t_{avg} = \frac{\frac{t_0+t_i}{2} + \sum_{i=1}^{i-1} t_i}{(i)} \quad (3)$$

Since (i) (Δw) is equal to the width w, the cross-sectional area becomes equal to wt_{avg}.

Henceforth, the average thickness is designated by t, and subscripts on t and w refer to the stations. The amounts of granular material on a road may be represented by a histogram in which the cross-sectional area is plotted against distance or station number (Fig. 2).

The addition of fresh granular material to a road increases the cross-sectional area as shown in Figure 3. By carefully controlling the quantities of material added to each section, the cross-sectional area of the total granular material can be made constant throughout the length of the road. The amounts of granular material can now be represented by the plot of cross-sectional area vs distance shown in Figure 4. Scarification to a constant depth (d) by using the fresh surface as a reference plane (see Fig. 3) then

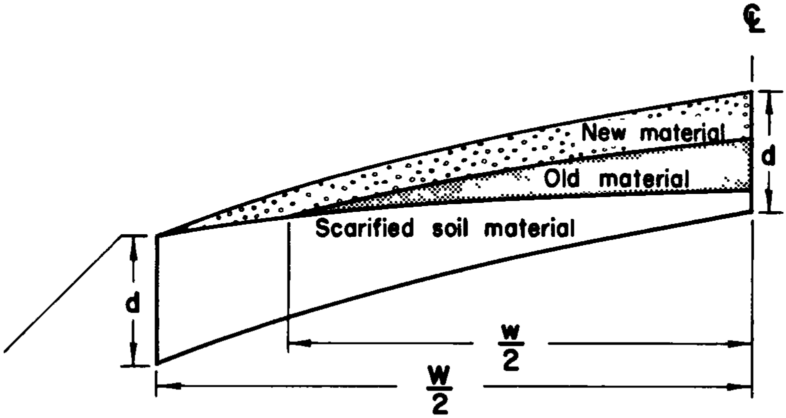

Figure 3. Cross-section of a roadway surface.

insures a constant cross-sectional area of loosened soil to be mixed with the overlying old and new granular materials.

Because the amount of any material in a section is the unit weight times the volume, the total amount of existing granular material G can be calculated by summing the amounts in each section.

$$G = \gamma_G \Delta L w_1 t_1 + \gamma_G \Delta L w_2 t_2 + \ldots\ldots + \gamma_G \Delta L w_n t_n + \gamma_G (L - n\Delta L) w_n t_n \quad (4)$$

in which L = total length in feet;
ΔL = length of a section in feet;
n = number of sections; and
γ_G = average unit weight of the in-place granular material in pounds per cubic foot.

The final term represents a remainder that must be included, because the length of a section is seldom an exact divisor of the length of the road. The values of the last trench sample w_n and t_n are assumed to also represent the final segment. Because γ_G and ΔL are constant, they may be factored from the equation so that

$$G = \gamma_G \Delta L \sum_{n=1}^{n} w_n t_n + \gamma_G (L - n\Delta L) w_n t_n \quad (5)$$

The quantities of materials necessary for a desired final mixture must be proportioned by some means. Davidson and Sheeler (2, 3) indicate that the plasticity index of a given type of soil is linearly dependent on the amount of clay present in the soil. The relationship is also dependent on the type of clay mineral. If a given soil changes in gradation from place to place but the type of minerals remains constant, the linearity of the plasticity index to clay relationship is preserved. The amount of clay contained by the materials then appears to be a useful control factor. The percent clay to be expected in a mixture of old granular material, new granular material, and scarified soil is given by

$$p = \frac{\frac{p_G}{100} G + \frac{p_A}{100} A + \frac{p_S}{100} S}{G + A + S} \times 100 \quad (6)$$

in which G = quantity of in-place granular material in pounds;
A = quantity of added granular material in pounds,

S = quantity of scarified soil in pounds;
p = desired percent clay in the final mixture;
p_G = clay content of G, percent;
p_A = clay content of A, percent; and
p_S = clay content of S, percent

Revision of Eq. 6 gives

$$S = \left(\frac{p - p_G}{p_S - p}\right) G + \left(\frac{p - p_A}{p_S - p}\right) A \quad (7)$$

or

$$S = K_G G + K_A A \quad (8)$$

in which

$$K_G = \frac{p - p_G}{p_S - p} \quad (9a)$$

and

$$K_A = \frac{p - p_A}{p_S - p} \quad (9b)$$

If the final dimensions (in feet) of the road are to be T = thickness, W = width, and L = length, and the material is to be compacted to a unit weight γ (in pounds per cubic foot) the total weight of the road must be γ LWT or the sum of G, S and A from which

$$\gamma \text{ LWT} = G + S + A \quad (10a)$$

Substitution of Eq. 7 gives

$$\gamma \text{ LWT} = G + A + (K_G G + K_A A) = (1 + K_G) G + (1 + K_A) A \quad (10b)$$

Rearranging Eq. 10b shows the necessary addition to be

$$A = \frac{\gamma \text{ LWT} - (1 + K_G) G}{1 + K_A} \quad (11)$$

To control the cross-sectional area throughout the length of a road so that the cross-sectional area of the scarified soil will also be constant at all points, several more equations must be developed. This may be done by using a synthetic average unit weight γ_{AG} of the new granular material plus the in-place granular material. The total weight of these materials is given by $\gamma_{AG} L \text{ (wt)}_{avg}$ where wt_{avg} represents the average cross-sectional area produced if the two materials were combined and spread evenly over the length L and compacted to γ_{AG}. The total weight is also given by G + A. The average unit weight is the total weight divided by the total volume so that

$$\gamma_{AG} = \frac{G + A}{\frac{G}{\gamma_G} + \frac{A}{\gamma_A}} = \frac{\gamma_A \gamma_G (G + A)}{\gamma_A G + \gamma_G A} \quad (12)$$

Also, $\gamma_{AG} L \text{(wt)}_{avg} = G + A$ (13)

Substitution of Eq. 12 in Eq. 13 gives

$$\text{(wt)}_{avg} = \frac{\gamma_A G + \gamma_G A}{\gamma_A \gamma_G L} \quad (14)$$

Eq. 11 gives the amount of fresh granular material required to add to the existing granular material and the scarified soil to make a road with a unit weight γ, a thickness T, a width W, and a length L. The depth of scarification required to give the weight of soil S necessary to produce a roadway surface of these dimensions can be found as follows:

Wd = total area scarified, square feet;
$(wt)_{avg}$ = area of granular material, square feet; and
$Wd - (wt)_{avg}$ = area of scarified soil, square feet

The weight of the scarified soil is then

$$S = \gamma_S L \left[Wd - (wt)_{avg} \right] \tag{15}$$

Substitution of Eq. 8 in Eq. 15 gives

$$d = \frac{K_G G + K_A A}{\gamma_S L W} + \frac{(wt)_{avg}}{W} \tag{16}$$

All equations necessary for the calculation and distribution of all quantities of materials have now been derived.

SAMPLE PROBLEM

The proper use of the equations is illustrated by working through a sample problem. First, the trench sample data (widths and thicknesses) must be obtained as well as mechanical analyses and unit weights of the soil and aggregates. The trench sample data are best obtained by digging short trenches on opposite sides of the road to locate the edges of the granular surface. Then, assuming that the cross-section is symmetrical, the trench is extended from one side of the center of the road, and the necessary measurements for computing the average thickness are taken and the width measured. Errors introduced by the symmetry assumption can be minimized by trenching on alternate sides. Baylard (1) used a similar system in a performance study of calcium chloride-treated roads.

The mechanical analyses and unit weights of the subgrade must be determined as well as the same values for the granular material to be added. The unit weight of the additional granular material γ_A must be determined in a noncompacted state, because this is the way in which the material will be used before mixing.

The trench sample data used to illustrate the application of the equations are given in column 2 of the schedule of materials in Table 1. The values of w and t have been determined and appear as w times t in column 2. The trench samples are 500 ft apart, the proposed road will be 3.5 in. thick, compacted to 130 pcf over a width of 24 ft and a length of 1 mi. The unit weights of materials are as follows: the in-place granular material is 130 pcf, the additional granular material is 100 pcf (noncompacted), and the in-place soil is 98 pcf. The proportioning of materials will be on the basis of a 9 percent 5-μ clay content in the final mixture. The mechanical analyses and plasticity indexes of the three materials are given in Table 2 which shows the 5-μ clay contents of the materials as 6 percent p_G, 3 percent p_A, and 30 percent p_S. A specified minimum addition rate of new material is 500 tons per mile or 47.35 tons per 500-ft section which amounts to a cross-sectional area of 1.89 sq ft for a 500-ft section (calculated with γ_A = 100 pcf).

The control coefficients are calculated from Eqs. 8 and 9b as follows:

$$K_G = \frac{p - p_G}{p_S - p} = \frac{9 - 6}{30 - 9} = \frac{3}{21} = \frac{1}{7};$$

$$K_A = \frac{p - p_A}{p_S - p} = \frac{9 - 3}{30 - 9} = \frac{6}{21} = \frac{2}{7};$$

$1 + K_G = 8/7$; and

$1 + K_A = 9/7$.

The total weight of the in-place granular material is found from Eq. 5:

TABLE 1

SCHEDULE OF MATERIALS

Station	$w_n t_n$ (sq ft)	Remove (sq ft)	Remove at 130 Pcf (tons)	Possible to Add Old Material Sq Ft	Possible to Add Old Material At 100 Pcf (tons)	Add Old Material at 100 Pcf (tons)	Source of Material in Col 7 (station)	Old Material Added (sq ft)	Total Old Material (sq ft)	Add New Material Sq Ft	Add New Material Tons	Corrected Addition (tons)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
2 + 50	2 50								2 50	4.07	101 8	102 6
7 + 50	2.12								2 12	4 45	111 2	112 0
12 + 50	2.59								2 59	3 98	99 5	100 3
17 + 50	2 37								2 37	4 20	105 0	105 8
22 + 50	4.12								4 12	2 45	61 3	62 1
27 + 50	3.81			0 87	21 8	21 8	32 + 50	0 87	4 68	1 89	47 3	48 1
32 + 50	5.97	1 29	41 9						4 68	1 89	47 3	48 1
37 + 50	4 24			0 44	11 0	11 0	32 + 50	0 44	4 68	1 89	47 3	48 1
42 + 50	2 71			1 97	49 3	9 1	32 + 50	0 36	3 07	3 50	87 5	88 3
47 + 50	2 79								2 79	3 78	94 5	95 3
	33 22											
52 + 50	2 51								2 51	4 06	56 8	57 3
			41 9			41 9					859 5	868 0

$$G = (130)\ (500)\ (33.22) + 130 \left[5{,}280 - (10)\ (500)\right] (2.51)$$
$$= 2{,}159{,}300 + 91{,}400 = 2{,}250{,}700 \text{ lb.}$$

The amount of additional aggregate material needed is found from Eq. 11:

$$A = \frac{(130)\ (5{,}280)\ (24)\ (3\ 5/12) - (8/7)\ (2{,}250{,}700)}{9/7} = 1{,}736{,}400 \text{ lb} = 868.2 \text{ tons.}$$

The average cross-sectional area after the addition of all material is found from Eq. 14:

$$wt_{avg} = \frac{(100)\ (2{,}250{,}700) + (130)\ (1{,}734{,}400)}{(100)\ (130)\ (5{,}280)} = 6.57 \text{ sq ft.}$$

Because the specified minimum addition rate is 500 tons per mile, which makes a cross-section of 1.89 sq ft, the maximum cross-sectional area to which 1.89 sq ft can be added to give the average cross-section is 4.68 sq ft (6.57 - 1.89). This value is then compared with those in column 2 of Table 1, and the value at station 32 + 50 is found to exceed 4.68 by 1.29 sq ft which is entered in column 3 and converted to tons in column 4 by

$$\frac{1.29 \text{ sq ft} \times 500 \text{ ft} \times 130 \text{ pcf}}{2{,}000 \text{ lb per ton}} = 41.9 \text{ tons.}$$

Column 5 is found by subtracting the values in column 2 from 4.68 sq ft. Only the sections immediately adjacent to the station having a surplus of material need be considered. The values in column 5 are then converted to tons in column 6 and an allocation of this material is made in column 7. The sum of the values in column 7 equals 41.9 tons in this case. If there were several surplus stations indicated in column 4, the sum of the tons of redistributed material indicated in column 7 should equal the sum of the surplus in column 4. Column 8 indicates the source of the material in column 7. The values shown in column 7 are converted back to square feet and entered in column 9. The values in column 9 are added to those in column 2 to give the total cross-sectional area of old material in each section after redistribution.

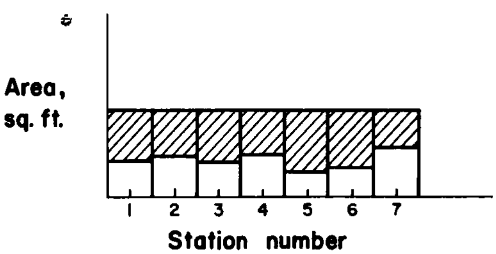

Figure 4. Histogram representing constant cross-sectional area of granular material after new granular material has been added.

Column 11 is found by subtracting the values in column 10 from 6.57 sq ft, the final cross-sectional area of the aggregate only. The values of column 11 converted to tons are entered in column 12.

The sum of column 12 will be slightly less than the calculated amount of additional material. The difference is mainly due to

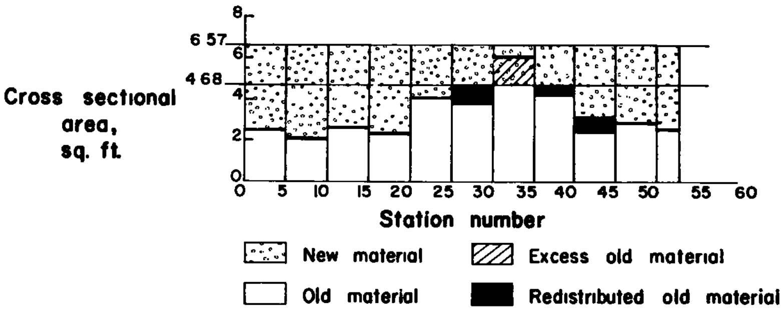

Figure 5. Sample problem cross-sectional areas of granular material after redistributing old material and adding new material.

the change in volume caused by redistributing the in-place granular material. The change in volume involved in this example is an increase of 0.3 cu ft per cubic foot of in-place material moved. This means then that for every cubic foot of in-place material moved the amount of fresh material must be reduced by 0.3 cu ft to stay within the computed constant cross-sectional area. The discrepancy also partially results because the number of significant figures does not permit a completely accurate material accounting.

The calculated additional material was 868.2 tons, which is 8.7 more than the sum of column 12. A correction is made by distributing the difference evenly to each of the sections to give column 13. This amounts to about 0.8 ton per 500-ft section and 0.5 ton for the final 280 ft. The sum of column 13 is then 868.0 tons, which agrees more closely with the calculated addition.

The final disposition of all granular material is shown in Figure 5. The example problem shows only one station with an excess of in-place granular material in order to simplify the calculations. Figure 5 is a graphical representation of Table 1 and is included to show more clearly the means of obtaining a constant cross-sectional area over the length of a road before scarification. A constant amount of soil is then assured.

After scarification, the soil and aggregate should be mixed. Any chemical stabilizer can then be added and mixed with the soil materials before final spreading and compaction.

The depth of scarification is calculated by Eq. 16:

$$d = \frac{(1/7)\,(2{,}250{,}700) + (2/7)\,(1{,}736{,}400)}{(98)\,(5{,}280)\,(24)} + \frac{6.57}{24}$$

$$= 0.0658 + 0.2738 = 0.3396 \text{ ft} = 4.075 \text{ in.}$$

Roads with a stabilized surface course must be constructed according to some set of specifications which usually include gradation limits and plasticity index limits. The gradation of the mixtures resulting from the calculations are compared with the gradation specifications of the Iowa State Highway Commission (4) in Figure 6. Because the amount of scarified soil is constant in all sections, the sections in which there was a minimum and a maximum amount of in-place granular material will represent the extremes of gradation in the completed road.

The outer smooth curves of Figure 6 represent the gradation limits specified by the "Standard Specifications" of Iowa (4) for stabilized surface courses. The two inner curves represent the gradations of the extremes previously mentioned. The two extremes fall well within the necessary limits. The dust ratios of the two mixtures are 0.57 and 0.55 (minimum and maximum in-place material, respectively) which are also well below the specified (4) maximum value of two-thirds.

The equation used to calculate the plasticity index of the two extreme gradations does not predict the exact value of the plasticity index but gives an approximation (6). The PI calculated for the section with a minimum in-place material is 9.5, and that for the maximum in-place material is 9.3. Both of these values lie well within the specified (4) range for a plasticity index of not less than 5 or more than 12. A quick

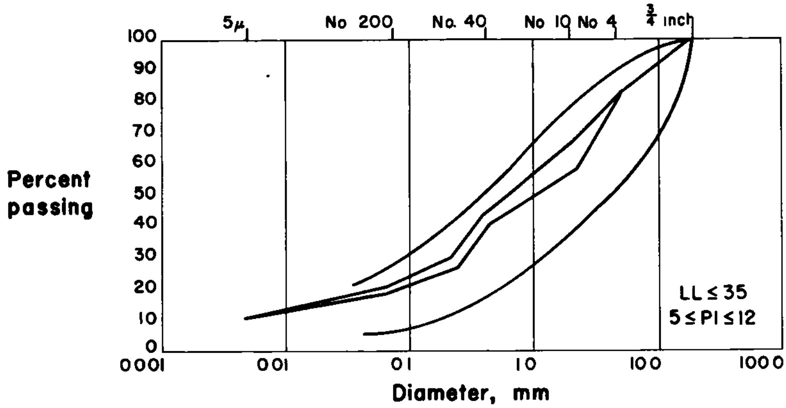

Figure 6. Comparison of gradations of final mixtures with limits specified. Smooth curves represent limiting values.

check on the calculated values can be made with Eq. 10 by

$$T = \frac{(8/7)\ (2,250,700) + (9/7)\ (1,736,400)}{(130)\ (5,280)\ (24)}$$

$$= 0.2917 \text{ ft} = 3.4999 \text{ in.}$$

which corresponds to the design thickness.

The thickness of the various sections will differ because the material is proportioned by cross-sectional area rather than by weight. After redistribution and addition of fresh material, there are essentially four different materials which are defined by cross-sectional area and density. These materials are loose (redistributed) old granular material at γ_{GR} pcf, compacted old granular material at γ_G pcf, loose new granular material at γ_A pcf, and compacted soil at γ_S pcf.

If these materials are combined and compacted to a unit weight γ, the total material in any section is $(\Delta LWR\gamma)/12$, where R is the resulting thickness in inches. The total material is also the sum of all the materials just described. The two can be equated as follows:

$$(\Delta LWR\gamma)/12 = \Delta L(wt)_S\gamma_S + \Delta L(wt)_A\gamma_A + \Delta L(wt)_G\gamma_G + \Delta L(wt)_{GR}\gamma_{GR} \qquad (17)$$

in which the subscripts on the cross-sectional areas (wt) correspond to those on the unit weights γ.

If $\gamma_{GR} = \gamma_A$

and $(wt)_A + (wt)_{GR} = (wt)_{avg} - (wt)_G$,

then substituting in Eq. 17 gives

$$(\Delta LWR\gamma)/12 = \Delta L\left[(wt)_S\gamma_S + (wt)_{avg}\ \gamma_A + (wt)_G\ (\gamma_G - \gamma_A)\right]$$

Substitution of the values from the example gives

$$R = 1/2\left[1.19 + 6.57\ (100/130) + (wt)_G\ (130 - 100/130)\right]$$

$$= 3.12 + 0.115\ (wt)_G.$$

The cross-sectional area $(wt)_G$ represents only the undisturbed granular material, after redistribution in any one section. The final compacted thickness at each station is given in Table 3.

Comparison of the thickness of the various sections shows them to be very near the design value of 3.5 in. in all cases. The greatest deviations are 0.14 in. below and

TABLE 2

MECHANICAL ANALYSES AND PI

Analysis	Diameter (mm)	In-Place Material (G) (%)	Soil (S) (%)	Additional Material (A) (%)
Sieve:				
3/4-in.	19.05	100	100	100
No. 4	4.76	79	91	78
No. 10	2.00	66	88	40
No. 40	0.42	37	72	24
No. 60	0 25	28	66	14
No 200	0 074	18	55	11
5μ	0.005	6	30	3
PI		5	21	2

0.16 in. above the design value, giving a maximum over-all difference of 0.30 in. between the thinnest and the thickest sections in the road.

REMARKS

The amount of 5-μ clay was used as the design criterion because it frequently correlates well with the plasticity index of a material. Nine percent clay was chosen, because research data indicate this to be the average amount of clay used in secondary roads in Iowa. However, the method of design described is not necessarily restricted to the use of the amount of clay as the design criterion but does depend on some size fraction. The size fraction used will depend on experience with local materials or perhaps on a conveniently determined size fraction such as the amount of material passing the No. 40 sieve or the No. 200 sieve. Known correlations of plasticity index with the size fractions may possibly influence the choice. If there are no correlations, the best size fraction for control can be determined by making trial mixes and correlating the amount of the various size fractions with the plasticity index. The equations still hold regardless of the size fraction used for control; however, the values of the constants, K_G and K_A, change accordingly, which in turn change the relative proportions of materials.

Several assumptions are made that are not strictly true and therefore introduce errors. However, if the assumptions are understood, the errors can be kept within the bounds permitted by specifications. The main variation occurs in gradation and hence in plasticity index, but because considerable leeway is usually allowed in these items, the quantities of materials can be controlled so that the final variations lie within the allowable range.

Some error is introduced by assuming that the histogram developed from trench sample data truly represents each section. The error thus introduced is not serious provided the difference between ordinates of adjacent sections is not too large. Large differences indicate that the trench samples are too far apart, and the distance between sites should be reduced. Occasionally a sample site will fall at an intersection and will show an excessive cross-sectional area. Samples should not be taken at or too near an intersection for this reason but should be taken on either side to describe adequately the quantities of material.

Another source of error in the histogram is in the fact that there is a tendency for the granular material to be bladed off the top of hills. The histogram will give a false representation of the amount of material on such a crest if the trench sample is taken elsewhere. If this discrepancy is not corrected, the final mixture will contain too much fine material and is apt to be too soft for good performance.

Other sources of error are due to the use of average values of density and gradation. Density values generally do not vary greatly from place to place for the in-place granular material, the in-place soil, or fresh bulky granular material. The use of an average value of density to describe the in-place material plus the added material introduces some error, but this is not too serious as indicated by the final thicknesses previously calculated.

TABLE 3

FINAL COMPACTED THICKNESS AT EACH STATION

Station	$(wt)_G$ (sq ft)	R (in.)
2 + 50	2.50	3.41
7 + 50	2.12	3.36
12 + 50	2.59	3.42
17 + 50	2.37	3.39
22 + 50	4.12	3.59
27 + 50	3.81	3.56
32 + 50	4.68	3.66
37 + 50	4.24	3.61
42 + 50	2.71	3.43
47 + 50	2.79	3 44
52 + 50	2.51	3.41

Differences in gradation from place to place cause the most serious errors and variability in the final mixture. The new material is usually rather uniform as it comes from a gravel pit or stone quarry, thus gradation errors introduced from this source are small. The main gradation differences result from the in-place granular material and the underlying soil material at the various stations. Of these two, the differences in gradation found in the soil are the most serious, because the soil furnishes most of the fine material and therefore influences the plasticity index of the final mixture more than any other ingredient. The amount of fine material in the mixture can be kept within the allowable limits by adjusting the control percentage used as a criterion for proportioning materials. If a road passes through several soil types having wide gradation differences each area must be treated as a separate problem.

The success of this method of design depends on the success of the method of construction as well as on the use of the equations. The new material must be accurately spotted and spread to form a reference surface from which to scarify to a calculated depth. The depth of scarification must be constant over the entire length and width to insure a reasonably uniform final gradation and thickness of stabilized material.

Present methods of secondary road construction, in which old road surfaces are salvaged, rely chiefly on the judgment of the engineer. Arbitrary rates of addition of granular material are used, and the depth of scarification is an estimation. Such practice sometimes leads to poor quality roads, although after long experience some engineers achieve considerable success with these methods. The scheme described in this paper gives the engineer a means of control over the amounts of materials and permits a more effective usage of old road materials. The quality of the resulting surface course is more controlled, and a good deal of guesswork is removed from the design and construction procedures. However, the method must be tempered with common sense and the engineer must be alert to recognize any deviations from the predicted results and should make field corrections accordingly.

ACKNOWLEDGMENT

The material presented in this paper was derived for use in a part of the research efforts of Project 375-S of the Iowa Engineering Experiment Station of Iowa State University. The project, entitled "Characteristics of Chemical Treated Roadway Surfaces," is sponsored by the Iowa Highway Research Board of the Iowa State Highway Commission.

REFERENCES

1. Baylard, E.M., "Performance Study of Calcium-Chloride Treated Roads." HRB Proc., 31:336-348 (1952).
2. Davidson, D.T., and Sheeler, J.B., "Clay Fraction in Engineering Soils: III. Influence of Amount on Properties." HRB Proc., 31:558-563 (1952).
3. Davidson, D.T., and Sheeler, J.B., "Further Correlation of Consistency Limits of Iowa Loess with Clay Content." Proc. Ia. Acad. Sci., 64:407-412 (1957).
4. "Standard Specifications." Iowa State Highway Commission, Series of 1960.
5. Ritter, J.B., and Shaffer, L.R., "Blending Natural Earth Deposits for Least Cost." Jour. Construc. Div., Proc., ASCE (March 1961).
6. Spangler, M.G., "Soil Engineering." 2nd ed., International Textbook Co. (1960).